

Indigenous Papua New Guinea Knowledges Related to Volume and Mass

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This paper is a distillation of part of the ground-breaking systematic recording of measurement data from many Indigenous communities of Papua New Guinea. It focuses on thinking during mathematical activities that relate to volume and mass. Implications for teaching measurement and making the implicit knowledge of students explicit are discussed.

Introduction

Papua New Guinea is rich in a diversity of cultures with their own languages and customs. For many years the Glen Lean Ethnomathematics Centre has been working to record much of the Indigenous knowledge related to mathematics of different language groups, analyse it and share the findings with teachers and mathematics educators. The Centre and education authorities in PNG encourage teachers to discern the Indigenous knowledge of those whom they teach in order to focus on cultural context. The counting systems of some of the 800 languages was recorded and analysed by Lean (1993) and disseminated by members of GLEC (e.g. Owens, Kaleva, & Matang).

This paper synthesises and evaluates the mathematical practices and thinking related to volume and mass. These are perhaps the two mathematical attributes generally referred to by the word “size” or “big” and “small”. Some of the linguistic features are also noted in this paper. However, even in using the words “volume” and “mass” in the title of this paper indicates the colonisation of knowledge by Western schooling (Smith, 1999). The school notion that there are systematic ways of calculating volume and mass may restrict participant researchers’ arousal of other mathematical ways of thinking.

Research Design

Ethnographic study is appropriate to investigate “ways of acting, interacting, talking, valuing, and thinking, with associated objects, settings, and events (that impact on) ... the mental networks” that constitute meaning (Gee, 1992, p. 141). Data is being collected and analysed and the analysis checked with data from other participants and communities as the grounded theory develops. Our research project requires participants who are familiar with their own communities’ activities and preferably investigating their own cultural practices. We are conscious of the various relationships between ourselves, the participants and the village elders whom we interview with a participant researcher (Owens, 2006). Villages referred to in this paper come from a variety of environments (mountains, coastal areas and large valleys) and language types (Austronesian and non-Austronesian languages). For this paper, data from 16 in-depth interviews (demonstrations, discussions, and observations with some semi-structured questions) either in the village (visited by at least two researchers), at the University of Goroka or with linguists have been complemented by questionnaire and focus group data.

Case Studies of Activities that Relate to Volume

In our preliminary examples from the highlands region, the link between volume and mass is evident. The notion of a big pig is primarily about volume but it has mass and more importantly fat. Pigs may be carried but what is seen is volume. Techniques are used to assist with the estimation of volume size. Like school mathematics, measures of length may be used to help with estimating volume. At school, calculation of volume is initially around the rectangular prism with the associated calculation of length x width x height to obtain cubic units. Many times there is little looking and estimating to compare sizes in terms of a ratio of those sizes. However, in the villages of PNG, we find practices in which a length measure can be associated with a volume. In our first example on pig fat, it is indicated that the width measured in fingers can be associated with the amount of fat/oil obtained in terms of bamboo lengths. While the connection is not given a multiplicative number, experience indicates how much one could estimate. “All the fingers were used to measure the pig fat and records were kept”. “The sheets of fat from the pig would be stripped of the membrane allowing the fat to run into bamboos. They would also boil it to get the oil. They might get four bamboo containers from a big pig” (Kamano-Kafe speakers from the Kainantu district of the Eastern Highlands Province [EHP]—4 men and 2 women and a group of people).

Another instance where lengths are used to measure volume is that of pigs. Although sight and ordering by sight is frequently done, some people mention that they look to see how close the belly is to the ground. Some participants mentioned measuring the length to the thigh or waist. The Kamano-Kafe mentioned the arms are used to measure the girth of the pig to see how far apart the fingers are when placed around the pig. There can be much discussion about the comparative sizes. In other places, the women keep the record of the girths by holding onto the string used to measure until it is needed again. If the length of the girth indicates the volume of the pig, then the link between girth and volume is not necessarily determined numerically but visually and it is associated with a range of other pig features.

From the Angal speaking areas of the Southern Highlands Province (SHP), “when measuring a pig size, a small rope was used to measure the size around the pig and also the length of the pig. Then they can weigh out the cost in terms of how much fat or meat it contains”. “In Imbongu culture (SHP), when a community is involved in moka, brideprice, pig killing etc, firstly they use sticks in a row to match the number of pigs to be killed. Matching is involved here. Secondly comes counting involving fractions and whole numbers. There is a very special way of counting in fractions. If one says "ekondo of a pig, it denotes one quarter. ekondo-ekondo means half for a slaughtered whole pig when shared among people. It is obvious that a whole can be slaughtered and cut into four quarters and then into smaller parts depending on with whom they want to share. If these payments of pork were put together, we get a whole pig. Therefore, the idea of addition, multiplication, subtraction and division of fractions is involved one way or the other. Thirdly, measurement of the length, width and thickness of the pork meat is considered by whoever is sharing and cutting. The family with more members take meat heavier and bigger than the ones with less members” (Veronica Kerapi, 2007). This discussion about quarters and even implying a quarter as a unit that can be combined or partitioned illustrates the influence of schooling but also how comparison and measurement are embedded in the activity.

Comparisons of size are made with existing things by looking. A big kaukau is matched with two smaller ones. Participants from several language groups mentioned that a small pig would require another pig added to match a big pig. “Food piles were also compared by elders, especially on deciding greatest and smallest piles” said a Kamano-Kafe speaker. “A hundred is a heap, with two hands together, giving a link to volume” (2 Siane men, EHP).

From the neighbouring area, a Fore speaker mentioned that the volume of taro is discussed in the following way. “People weigh (by hefting with the hands) the heaviness and lightness, length (long or short) and size (big or small) and finally group them in order of their size, length and weight:

- Heavy, long, big
- Heavy, short, big
- Light, long, small
- Light, short, small”

The Fore speakers (4 men and 1 woman) provided some measurement words discussed in a later section.

From the mountains on the northern side of the Finisterre Range of the Madang Province a Yupna man reminds us that the comparison of pig size was linked to cultural ceremonies. “Bride price payment is one of the famous ways of uniting two different parties together. They pay the price with different wealths either modernized or traditional. They also have different ways of arrangement, preparation and payments. However in my culture, the traditional wealth is of less significance. Upon the display of items, the length of items, traditional money, the pigs and bunch of banana are measured. They use ropes and bamboo nodes to measure the length and sizes of food stuff and pigs. They use two different ropes, one is longer than the other to measure the length of the pigs and the yams. One hand span (arm span) of beads, is equivalent to two smaller female piglets and half of the beads (from finger tip to middle of the chest) is equivalent to two male piglets. Although they have a digit tally counting system, they will also tie knots for each of the pieces of wealth with different ropes for each kind of wealth. They use a chain of dogs’ teeth to measure the beads used for making the payments. They associate these with the length of the beads and the money displayed. These kinds of payments are also used for land disputes.” It is clear from this description that lengths are used in conversations to make decisions about the size or volume of items and to make judgements about the wealth or value of the objects.

A Kumbu (or Kewapi, SHP) participant mentioned that the size of the kaukau bilum (string bag) will be discussed by up to 40 people which he compared to the 400 who might be involved in deciding the area of land. When ceremonies are held in many places, the number of pigs, bilums, baskets and mounds of food are compared. Size is only one factor that might be taken into account. For example, for the Arop in Sandaun Province, it is the number that predominates. However in the exchanges of baskets and bilums of food, the type of food also matters as mentioned by several coastal villagers around Madang.

A Yupna man noted that small volumes were considered when making medicines. “There were many different kinds, for worms, colds, sores. Ginger was used for colds. It was broken up by hitting, squeezed through a strainer and mixing with just a teaspoon of water. From one of the kunai grasses with a smell, they take the skin away and use the hard inside, may be five of these and boil in hot water. Then they give half a cup to a child and a full cup to an adult. For cooking, they would use a small amount or too much and remember to improve it for next time.” The experiment was a recognised approach to using volumes. The same idea has been mentioned by Yu Woi or South Whagi speakers for making the red marita pandanus sauce and by coastal dwellers for achieving a good mix when mixing sago pulp with water, straining it and leaving the sago starch to settle out from the solution.

Length is also used to refer to the volume of holes. A Keyagana man mentioned “a circular rope and long stick are used to measure the volume of a pit toilet.” By contrast, a Kamano-Kafe lady mentioned lengths to refer to volume for both the depth of a major drain (the height of a man then marked by a length of pitpit). She also noted a piece of rope was used to measure larger and smaller bilums.

Many participants from many highland areas referred to volume in describing the amount of water needed for a mumu cooking pit. The mumu is ubiquitous although the methods vary slightly within the highlands region while the methods for coastal areas are quite different. The Fore participants described the scene for a ceremony. The elders decide the amount by feeling the heat and decide how much water is needed. The bamboo is selected by its width and length of nodes. A Kamano-Kafe speaker put it the other way round “bamboo was measured by the amount needed for a mumu pit”. Bamboo lengths were used for carrying water to the mumu pit. The size of the pit and heat (resulting from the type and amount of wood used and stones) would determine the amount of water to be added to the covered heated stones until the steam rising from the watered stones slowed down and provided steam for the cooking. Figure 1 shows steps in the mumu preparation. In this case, the river was very close and five cooking pots were used.



Figure 1. Making a mumu in Kaveve (photographs courtesy of Annica Andersson)

Further west in EHP, is the town of Goroka surrounded by Alekano (Gahuku-Asaro) speakers. Six men mentioned small mumus are made regularly for family consumption and to cook nuts. “Water for a mumu will need to be around five bamboo stems with at least five nodes in each. Today, a very hot, large mumu will require around five very large pots of water.” These conversations were confirmed by the observations and discussions held at Kaveve village in this language area. The actual size of the mumu pit was also compared. “The fire for the mumu pit will be two to three times bigger than the house fire while the family ceremony mumu will be two or three times bigger again. They use two to three bamboo lengths (twice the length of a man) for the family mumu pit” (4 men from neighbouring Bena).

At the western end of the Eastern Highlands, the Tokana speakers indicated “sticks are used for the depth of a mumu pit so that the amount of food will be suitable. The volume of the bamboo which is carried by women for water is also worked out depending on the heat of the stones. The amount is usually determined by the elder men. The bamboo is considered as a container for volume.” The Imbongu speaker also mentioned that in digging the earth oven pit, the foot of a person is used to measure the length and width of the pit. The toe to the knee was used to determine the depth of the pit. People would vary the size of the pit and its shape to suit the number of people to be fed. When pigs are being cooked for large feasts, the pit is likely to be a long rectangular prism. Familiarity with different types of mumus, different sizes, different woods and different foods are all combined in the knowledge used by the elders to make decisions. Part of the knowledge is the notion of volume.

Participants throughout the highland areas where round houses are built referred to the volume of the house in terms of cold or “cargo inside the house” (Keyagana man). Lower levels were spaces for food, fire, sleeping, and spreading out drying nuts whereas the upper levels (at chest height) were for baskets of nuts, pots, smoked pig, and other possessions (Figure 2). In addition they mentioned the importance of getting the size right. The round houses, heated by a central fire, are not big so the cold does not penetrate. Conversations about the resultant size of the house and the necessary radius of a circular house were frequent among highlands men involved in building round houses. Similar conversations were held about the floor plans for rectangular houses in other highland places.



Karaku nut basket being made;

Baskets of nuts in ceiling of house;

lower level with cargo spread out during the day

Figure 2. Volume of a house and karaku basket.

House building is always associated with a feast to thank the helpers. The garden must be ready for the feast. People must be given more than enough. For a feast, they might have 20 parcels of kaukau and one pig for sharing. They plan when kaukau is ready to ask others to the feast. A grown man or woman needs four kaukau each. Others might also contribute to a feast to show their relationship with the person.

For coastal areas, there are different activities and available materials compared to the highland regions. In some highland areas where there are lakes and slow water courses, canoes may be made but generally these are found on coastal plains with outrigger canoes used by seafarers and on wide rivers like the Markham, Morobe Province.

Trading used to occur along the Madang Province coast from around Madang eastward. Malalamai is a coastal village four hours by speed boat east from Madang. Inland from Madang are the villages of Amele and Panim speakers while Bilbil (where pots were made) is on the coast close to Madang. Two small pots were traded for a large bilum of mixed garden food (Malalamai woman). A basket of yams would also be traded for two pots. There was a ratio of values. Amele speakers mentioned that they would trade a large bilum of taro for three clay pots. Pot makers, a participant from Bilbil commented “smaller baskets about 0.5m long, 1m wide and 0.5m high are distributed to ordinary people and the bigger baskets, the size twice as much as the smaller baskets are given to the elders-(kukurais). The sizes are remembered. The only length measurement being recognised is that of an average coconut”. Panim people provided some interesting details on feasts as an activity that considered size along with other factors.

When there is a feast, then the various families will bring food. The pigs will be tied to the sticks (“stik pik”) which are put in the ground, carefully indicating how many each line will get. Each group will get their share. When the pig is distributed, then all the men will check. Then a piece goes to each man and usually a coconut-leaf basket of food is used and distributed to each man in the group. Each basket has an opening about 50cm wide. There is a rope handle to put on a pole so it can be carried. For feasts, the family would

need very heavy bilums of mixed produce to share and trade. Each family would supply large bilums full of food. They would use big clay pots, make a hole in the ground for the fire and put the pots in the hole. It was important to prepare much more food than the men could eat and to prepare 5 to 7 plates full per person. Pots were made at the beach where the clay and sand could be used together whereas Panim was in the bush. They traded garden food for ground pots and never pigs. Usually 1 to 3 bilums of mixed garden food for one pot but they also took account of friendship. They would also trade eight or nine packets of sago wrapped in the bag made from the palm. They would trade bilums of different sizes for different size pots. They might buy three or four pots at a time.

The description indicates that volume is a key aspect of the trading but other factors such as type of food and relationships of people are affecting the exchanges.

In Kaveve, karuku nuts are stored in long tapering baskets (Figure 2). The weaving depends on the length of the bamboo that is split to a node at one end, the available space to store it in the ceiling of the house and the number of nuts to be stored. In the past, these baskets were given to the coastal people with whom they had relationships and were well regarded. The filling of baskets indicates volume. Nuts are frequently cooked in a mumu or stored over the fireplace so they can be kept for longer periods or sold to those who prefer the cooked nut. The monetary value of the nuts when sold at market can also be calculated. Cooking reduces the mass but not the volume.

From Abau in the Sandaun province, SIL linguist commented that a nok is the sago or coconut frond with sago grubs threaded on it. It is about a hand span (index to thumb) long. It was a standard familiar volume unit. It could also be considered a mass unit. The flour sack was used for many items – sago, coffee, vanilla and so on. It was a unit of volume. The Abau speakers wrap up six sago balls in a banana leaf and pack these into the limbom basket (made from the bark of a limbom palm – Figure 3) so it is like a composite volume units. The limbom basket is a regularly used measure of volume used for numerous purposes.

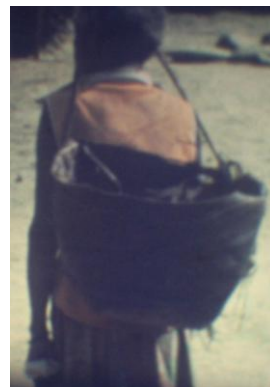


Figure 3. Bilums for carrying heavy masses of karuku nuts (Kaveve, Eastern Highlands Province) and limbom basket worn on the back (Wosera, East Sepik)

Other discussions about volume occurred in discussions about materials for house building, canoe making and fence making. In Malalamai, men know the trees on their land (swamps and forests as well as gardens) and they can look at a tree and picture the number of canoes and the length of the canoes or the house posts they will be able to make from it. A large tree like a Kwila tree is cut down and made into say 12 posts. After cutting the tree in say three places, then each is cut into the posts which are carefully smoothed and made round. The posts are put in the ground with the baseline of four along the house and rows of three across (see Figure 4). A big canoe would be bigger than putting your hands around the tree (Asat man). Observations indicated that the visualised length of a canoe was not generally associated with a specified number of arm spans although mentioned in terms of our

discussion as a possible way of measuring canoes but bamboo sticks were more likely to be used as they were longer.

Another activity to mention about volume relates to Kaveve women collecting around 30 bundles of kunai for the roof. It is folded over the ropes that wind around the poles that form the roof. Both in the highlands and in the coast where kunai is collected for roofs, people referred to knowing the area that would be cut to collect enough of that particular kind of grass for the roof of a particular house. In Kaveve, it was the round house but on the coast it was a rectangular house. The Yupna man from Gua (Madang Province) indicated the large number of kunai bundles and areas for collecting the kunai so that the large curved frame of the house was covered with kunai and looked like a huge stone from the distance.

Similar comments are also made about the collection of sago leaves for houses in the coastal regions. Malalamai noted that they can look at the limbom palm and know how many planks they can make for roofing. They can tell if a pile of morata (sago leaves sewn over limbom timber as roofing) is sufficient for half a roof of a particular house (Figure 4). (This is a recent innovation that spread from other places in the Pacific and around PNG). The Panim men commented that “they start the house by collecting the sago leaves and making the morata for the roof. For a 9 post house they will select five very big sagos ready to eat and more for a 12 post house, may be nine. If it ends up being insufficient, they will get more later. The morata are about one and a half arm spans long. This will influence the size of the house and a bamboo will be used to keep this length.”



Figure 4. Coastal house on posts with *morata* on the roof (Malalamai) and in preparation for a new house (Kela, Morobe Province).

Women can estimate how many bilums of different sizes they might make from a tulip tree or the length of cloth when the tulip inner bark is beaten for the tapa worn by men (from Malalamai and from Atzera speakers of the Markham valley, Morobe Province). The Malalamai women also know they are likely to need about 12 trees to make a grass skirt. This

information is known from previous experiences (Figure 5). The increases and decreases are estimated. These are both length and volume estimates. “In the past, when making long fishing nets they were stretched along the beach. The maker would make a row of knots starting with the special top knot (called centipede and also used for attaching the string to the waist of the grass skirt or kunai on the roof). Rows of holes are made like the volleyball net. Between 10 and 30 balls of string would be needed. In the past, this was all hand made from bush materials and twisting on the leg.” The amounts are relatively vague and mentioned for a discussion on mathematics and yet in practice those balls of string would be prepared for the purpose of making the required size net, a long and arduous task.



Grass skirt, bilum and dog's teeth head dress all made to fit the wearer; baby in bilum, morata under house, coconut frond basket for carrying small items.

Figure 5. Uses of bush materials for items with volume.

Further Links with Mass

It is difficult to distinguish between the importance of mass and volume in practice. The large clusters of karuku pandanus nuts provide good examples of mass. Women will carry considerable loads of these nuts in several bilums—around 15 nuts in total each weighing about 5kg (Figure 3). From the far end of the highlands in the Enga province, pandanus nuts are used for comparing size. A participant researcher commented:

A method of verbal description was used to make comparison with the item in terms of the weight of one pandanus nut. To work out or determine the mass of a certain item, it was only described or compared in terms of the weight of a pandanus nut. A kaukau bag was also used to make comparisons with its weight but it was not used as commonly as the pandanus method. Object that weighed only slightly more than a pandanus nut were described as more than one pandanus nut but less than two pandanus nuts. Likewise objects weighing less than one pandanus nut were described as equal to a half or a quarter of a pandanus nut. (Paeo Kare & Nimba Waringi,)

When the people from Malalamai made the fishing nets, floats were put every fourth hole and in the middle would be a carved fish “kakana” (the size of the ones to be caught) while at the bottom of the net would be sinkers made from shells. If the carved fish in the middle went

underwater then that would be enough fish in case the net broke. This is a good example of mass. In this case, an increase in volume will increase the mass.

Another example of fishing comes from the Tolai of East New Britain who speak Titutukana (also called Tolai and Kuanua). Fish baskets are weighed down with a mass of stones will be varied according to the size of the basket and the strength of the currents. From their experience they estimate what mass of stones to use (Patricia Paraides).

Mention of size and weight was made during discussions on traps in Malalamai. There are several kinds of traps. For one kind, especially for the bandicoot or ground bird, they will have a trap with side walls and one end enclosed. When the animal comes inside and moves around eating, it will release the stick that is holding the heavy plank that will fall down and kill the animal. The rope and hook have to be strong. Two forked sticks hold a horizontal stick on which the small sloping platform of sticks lies. This is covered and when it is lowered by the animal's weight, it releases the hook and drops the heavy plank. The other trap is made so the noose will spring and hold the leg of the bandicoot. This is a fairly small trap but for the pig it has to be bigger. When the noose gets the leg, the animal must swing freely in the air. The final kind of trap is a deep hole (about as deep as shoulder height at most). It is designed so the pig cannot move. The mouth is covered by sticks and material and when the pig crosses it, it will fall in and the owner will come and kill it. Another activity that the people related to volume was making woven bags from a coconut leaf (Figure 5). As a variation they had developed hats that started with a tight weave and then were made to fit the person's head which was seen as a volume as well as having a circumference. Weaving these bags is learned by younger men from the older men in the men's house.

Linguistic Comments

Each language has its own way of referring to sizes. Some have comparative words. For example, Korafe speakers in Oro Province use suffixes for “bigger” and “biggest”. They have a word for a pile *ai* but they also use metaphors for size. For example, a child is a chunk of the father or a smaller version of the father. In addition they will also use reduplication which is found for descriptive words (larger and/or smaller) and other purposes (e.g., continuing verb, plurals, groups like two by two, emphasis) in other languages. For example, Dobu further along the coast in Milne Bay Province uses the word *kaprika* for “pumpkin” which changes to *kapukapurika* for “small pumpkin” (Capell, 1943). Manam in Table 1 illustrates reduplication too. Other languages use a range of diminutives.

Obtaining vernacular words for size and other related ideas is complex. To begin with it tells us that people thought about size. However, participants often thought for some time before completing the word lists as there is probably not an exact match between English words and their own language for meaning nor necessarily the same kind of speech pattern. For example, the word may not be an attribute word or adjective. Mussau in New Ireland has an auxiliary clause (SIL linguist, personal communication). They also have the word “mother” to refer to large things. It is similar to the Huon Peninsular *awara*.

Issues arise with confirming the words. Most of the words in Table 1 are only one of the variants provided by speakers of the language. This is understandable given that villages often develop their own specific words and pronunciation and the languages are mostly oral with only recent recording if any. Table 1 also shows a number of different words for the same concept in English. Some of these can be explained in terms of the influence of other languages. For example, for Titutukana the word “to measure” includes *mak(ai)* which is similar to Tok Pisin (PNG's lingua franca) word and the overlap of words in the three highland languages (Huli & Kewapi in SHP and Enga) suggests inter-language influence.

Reduplication can be seen in the Manam words suggesting a different linguistic structure for representing size than some of the other languages except the other island language, Titutukana. One Huli speaker noted that volume was a combination of length, width and height (Philip Piru). The impact of western education might be evident in this comment.

Table 1

Example of measurement words from the Fore of the Eastern Highlands and Manam an island of the Madang Province

English	Fore	Manam	Titutukana	Enga	Huli	Kewapi
big	tave	taila, dadaka, memekei, kanabibia, ilaba	ngala (variations)	andaik, yale	timbuni	andai
compare	koviga	tongaka	varvadaina, vandadauane, valarue, varagopina	makande, kapakap	manda(pia)	anamealapa, manda- mamea
full	puma,e	ikaUri	buka	tubelam, tubabpah, tuimbilam, perperta	toho laya, caralipa, catlope, to	manda, rege- pe-lea, rayo
heavy	gunda	moatubu	mamat	kend, kenda, kendepi, kendaping	kend, kenda, kendepi	kend, kenda, kendepi
light	ewasa	malama	papa, papanga	yapalume, kende napinge	hale, je-pe- pi, emene, jepeapi, yapipi, atatapi	yapa-pea, pa
little	amanagando	kengekenge, sikisiki, mukumuku, seisei, bisibisi	kapakapana	kolam, kokilyam, yaalam	emene (various spellings)	egepusi, ekei, ekesi, ogesi
long	he'elo	salagabuli, salagauta,	lolovina	londe londe, londakai	luni	andalu...
measure	amakaga	tongaka	mak(ai), angewe, valarue	makande, makade	manda pia, kimagi, kemagi	mandamea
short	alo	tupeka	gur tutuk, ngu ngu, tutukana	moui, muu	tomaki	rundu(ai)(si)
size (volume)	mangawa'e	ilo	ngala	kapkap, makande	arane, timbuni, luni, taliga	ekei-yapa andai

However, the most overwhelming point to make is that these speakers could find words in their own language to express the English concepts. For some this might have been tentative as they recalled their first language (observation while questionnaires were being completed). In most cases, we have more than one person providing words for the language confirming the data.

Discussion and Conclusion

This paper provides the first recording of a range of events revolving around concepts of volume and mass across a number of language groups in Papua New Guinea. Similarities and differences were also found in other language groups but variations in practice within the group exist as well as across groups. In general, people referred to capacity or fluid amounts rather than the notion of a cubic unit. In the one case, where lengths for across, long and down were given for a mumu pit, the lengths were used as representative of other lengths that could be used, rather than in a way that could be combined (multiplied) to give the number of a fixed-sized cubic unit. Instead the size of the mumu pit was seen in terms of the food to be placed in it. If it was to hold more than one pig, for example, the hole would be longer.

While other mathematical features (e.g. the shape) of bilums, pigs, holes and houses were not mentioned in reference to volume, a length was seen as an important “rule-of-thumb” way of determining volume. For example, a length of string was linked to the volume of a bilum and the girth of a pig to its volume or hence its mass. Nevertheless, the lengths that were referred to in describing a house did recognise the basic shape of the house. Thus radii for round houses or lengths of the sides for rectangles were mentioned together with heights. Length was also the key for discussing areas (Owens, 2007).

Concepts are established by language so it is important to recognise the range of ways by which groups indicate measurement attributes. Taken-as-shared concepts develop through practice. For example, the regularity by which a sack, basket, pot, ball or packet of sago was used resulted in a relatively consistent unit of measure. Similar examples have been given for length (Owens, 2007). One should also note the sophisticated ability of people to estimate needed amounts, for example, water for mumus or garden areas. In each case, a good sense of comparative rates is applied based on previous experience rather than on a mathematical calculation of volume. For this reason, comparisons are frequently made and confirmed by a group of people when payment or decisions involving sizes of mass or volume are made. The visual reasoning dominates over the numerical reasoning although numbers will be called upon to support a discussion. In many cases, the number rather than the size will dominate so long as items are roughly equal in size (Abau and Yupna have made this comment). Nomographs and ready-reckoner tables are possible equivalents to these mentally stored Indigenous knowledges.

Quantities were provided on numerous occasions to indicate amounts but these were frequently indicative of approximations or possibilities like round numbers are used in western societies. This was particularly noticeable in the field trips. Pica, Lemer, Izard & Dehaene (2004) noted a similar effect among the Mundurukú speakers of the Amazon, South America when they mentioned “five” or “a handful” to refer to displays of five up to nine dots or using “four” or “a few” when five dots were presented.

The diversity and uncertainty by which speakers provided words for the commonly used school terms of volume, mass, unit and composite unit indicated that most communities needed to consolidate their Indigenous knowledge and determine how best to refer to these ways of thinking and acting in their language and then to appropriately link to school mathematics either by a clause, phrase or single word.

In most language groups, activities that relied on notions of volume and mass could be identified as a means of introducing the concepts to children. Most activities relied on comparative estimates that do not necessarily require a unit of measure. It is only by using objects such as pigs and houses, and re-enacting or observing the making of mumu pits or measure of a pig that teachers could then make links between practice and school mathematics.

Teachers could take an appropriate unit such as a karuku nut or bamboo length and discuss measurement of mass or capacity of objects. Volume was frequently linked to a single length measure and so discussion of volume resulting in an increase in the length needs to take place. Different pig sizes could be modelled with cylinders to assist students' understanding that enlarged shapes vary in relationship with increases in a particular linear unit if other dimensions are kept fixed. Rectangular mumu pits could be more easily modelled in terms of volume units if they were filled with standard packages or lengths of wood. It would be high school mathematical calculation linked to the shape of an object rather than elementary school when these issues could be further addressed and discussed. Then the transition between Indigenous knowledge and school mathematics could be completed rather than left in the important realm of comparative estimation without this being used to establish school mathematics.

It is important for students to realise what exactly is happening when a length is used to measure volume (often implying mass as in comparison of pigs) or area. Without enactment and discussion, students are likely to stop at a preliminary development of mass and volume and their units and not fully develop the concepts. Later work on estimating, calculating, decision-making and using mass and volume units would be severely limited. By contrast, a rich beginning to measurement embedded in cultural practices with follow up work during the whole period of school would result in enriched concepts assisted by complementarity of knowledges.

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